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(54) Method!and!apparatus!for!skin!rejuvenation!and!wrinkle!smoothing

(57) A!method!and!apparatus!for!treating!skin!Includes!applying!pulsed!light!to!the!skin!to!heat!and shrinking!collagen!within!the!skin,!thereby!reviving!the elasticity!of!the!collagen!and!of!the!skin.!The!epidermis and!outer!layers!of!the!skin!may!be!protected!by!cooling with!a!transparent!substance,!such!as!Ice!or!gel,!to!the skin.!The!temperature!distribution!within!the!skin!is!controlled!by!controlling!the!delay!between!the!time!the coolant!Is!applied,!and!the!time!the!light!is!applied,!by controlling!the!pulse!duration!and!applying!multiple!pulses,!and!by!filtering!the!light!and!controlling!the!radiation spectrum,!preferably,!the!spectrum!includes!the!light having!a!wavelength!in!the!range!of!600-1200nm.!The pulsed!light!may!be!incoherent,!such!as!that!produced by!a!flashlamp!(301),!or!coherent,!such!as!that!produced by!a!Nd(Yag)!laser!or!a!ruby!laser,!and!may!be!directed to!the!skin!using!a!flexible!or!rigid!light!guide!(305).

Also,!a!method!and!apparatus!for!cutaneous!resurfacing!including!directing!Er.YAG!laser!light!to!the!skin. The!light!may!be!pulsed, **preferably** with!a!delay!of!about 0.5-10msec!between!pulses.!In!one!embodiment!the pulses!have!energy!fluences!of!preferably!about!100J/cm^2.

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Description

The present invention relates generally to the art of skin treatment using **electromagnetic** radiation. More particularly, the invention relates to an efficient method and apparatus for skin rejuvenation by ablation of the outer layer of the skin and wrinkle smoothing (or shrinking) by heating of collagen without damage to the epidermis.

There is a strong desire today to obtain and/or maintain a youthful **appearance**. One manner of doing so is to remove (or reduce) wrinkles. Additionally it is desirable to **rejuvenate the** skin by removing an outer layer of skin. There are known techniques for removing wrinkles by peeling the skin. Also, there are known methods for rejuvenating the skin. Unfortunately, all known techniques suffer from lack of efficacy and risk to the patient

One known method of skin rejuvenation includes injection of collagen underneath the skin. This has been performed using a bovine collagen injection. For example, microfine collagen has been Injected Into periocular lines. Some of the problems with collagen injection include, allergy to collagen and lack of longevity. Also, often there is only partial eradication of the wrinkles.

Peeling most or all of the outer layer of the skin is another known method of rejuvenating the skin. Peeling can be achieved chemically, mechanically or **photothermally**. Chemical peeling is often carried out using trichloroacetic acid and phenol. An inability to control the depth of the peeling, possible pigmentary change and risk of scarring are among the problems associated with chemical **peeling**.

The mechanical method is called transcutaneous blepharoplasty and involves shaving off the outer layer of skin. Skin resection during lower lid blepharoplasty frequently results in undesirable side effects, especially ectropion and scleral show. Moreover, transcutaneous **blepharoplasty** rarely eradicates all of the wrinkle lines.

Pulsed carbon dioxide laser treatment is a known photothemhal method of removing of periocular wrinkles. However, laser light is heavily absorbed in water and has a very short range In the epidermis. Thus, a high fluence with short pulse durations will evaporate the outer layer of the skin and peels most or all of the epidermis.

The use of CO_2 laser light for skin rejuvenation also has undesirable side *effects.* For example, CO_2 lasers have small spot size (3mm or less), and thus their use causes valleys and ridges, particularly when resurfacing large areas. Also, it Is difficult to control heat diffusion, and thus the resultant necrosis is difficult to predict and control. Additionally, scar tissue absorbs CO_2 laser light differently than normal skin and thus may adversely Impact such a treatment.

Thus, it is apparent there is a need for a new method and device with which it is possible to produce *efficient* wrinkle removal and skin rejuvenation. This apparatus would preferably be able to control the treatment parameters according to characteristics of the tissue, and be easily tunable. The new method and device would preferably provide efficient wrinkle smoothing and skin rejuvenation with minimal side effects.

In accordance with one aspect of the invention a method and apparatus for treating skin includes applying pulsed light to the skin to heat and shrinking collagen within the skin, thereby reviving the elasticity of the collagen and of the skin. In one embodiment the method also Includes protecting the epidermis and outer layers of the skin by cooling the epidermis and outer layers of the skin. The cooling may be accomplished by applying a cooled transparent substance, such as ice or gel, to the skin.

In one alternative embodiment the skin is cooled by applying the transparent substance to the skin and then cooling it.

In another alternative embodiment the temperature distribution within the skin Is controlled by controlling the delay between the time the coolant is applied, and the time the light is applied. A microprocessor may be used for determining the delay time in **response to a selected skin temperature profile. Additionally, the temperature distribution may be controlled by controlling the pulse** duration and applying multiple pulses. In another embodiment the **temperature** distribution within the skin is controlled by filtering the light and controlling the radiation spectrum. Preferably, the spectrum includes light having a wavelength in the range of 600 1200nm.

In another embodiment the pulsed light may be Incoherent, such as that produced by a fiashlamp, or coherent, such as that produced by an Nd(Yag) laser or a ruby laser.

In another embodiment the light is directed to the skin using a flexible or rigid light guide.

In accordance with a second aspect of the invention a method and apparatus for generating a temperature distribution inside a region of skin having a maximum temperature at a selected depth includes cooling the epidermis and outer layers of the skin and applying pulsed light to the skin.

In one embodiment the cooling is accomplished by applying a cooled transparent substance, such as gel or ice, to the skin. Alternatively, the cooling may **be** accomplished by applying the transparent substance, and then cooling it.

The temperature distribution is further controlled in one embodiment by controlling the delay between the cooling and the light application. In another embodiment the distribution is controlled by controlling the pulse duration and/or applying multiple pulses.

In accordance with a third aspect of the invention a method and apparatus for cutaneous resurfacing includes directing Er.YAG laser light to the skin. The light may be pulsed, **preferably** with a delay of about 0.5-10msec between pulses. In one embodiment the pulses have energy fluences of preferably about 100J/cm^2.

In!accordance!with!a!fourth!aspect!of!the!invention an!apparatus!for!the!cutaneous!resurfacing!of!a!region of!skin,!including!skin!resurfacing!or!wrinkle!smoothing, Includes!an!incoherent!light!source!such!as!a!flashlamp and!an!Er.YAG!laser.!The!laser!can!be **operated** in!a multiple!pulse!mode.!A!delivery!system!delivers!the!Incoherent!light!and!laser!light!to!the!region!to!be!treated, and!the!region!may!be!cooled.

Other!principal!features!and!advantages!of!the!in**vention** will **become!apparent** to!those!skilled!In!the!art upon!review!of!the!following!drawings,!the!detailed!description!and!the!appended!claims.

Figure!1!shows!a!temperature!distribution!achieved inside!the!skin!after!a!cold!fluid!was!applied!to!the skin,!for!a!plurality!of!different!time!delays!after!the application!of!the!cold!gel;

Figure!2!shows!a!temperature!distribution!achieved by!precooling!the!skin!and!applying!the!light!source;

Figure!3!is!a!schematic!illustration!of!the!flashlamp light!source!according!to **one!preferred!embodiment** of!the!present!Invention;!and

Figure!4!shows!a!normalized!output!filtered!radiation!spectrum!of!a!flashlamp!light!source.

Before!explaining!at!least!one **embodiment** of!the invention!in!detail!it!is!to!be!understood!that!the!Invention is!not!limited!in!its!application!to!the!details!of!construction!and!the!arrangement!of!the!components!set!forth!in the!following!description!or!illustrated!in!the!drawings. The!invention!is!capable!of!other!embodiments!or!being practiced!or!carried!out!in!various!ways.!Also,!it!is!to!be understood!that!the!phraseology!and!terminology!employed!herein!is!for!the!purpose!of!description!and should!not!be!regarded!as!limiting.

The!invention!relates!to!a!new!method!and!apparatus!of!removing!wrinkle!and!rejuvenating!skin.!Generally, in **accordance!with!this!Invention,!wrinkles!are** smoothed!or!reduced!by!collagen!molecules!shrinking and!increasing!the!elasticity!of!the!skin!and!collagen, using!a!short!heating!impulse!(thermal!shock).!Tissue is!heated!at!a!depth!of!up!to!a!few!millimeters!by!light radiation,!while!the!skin!is!externally!cooled!at!the!surface!to!avoid!overheating!the!epidermis.!The!epidermis may!be!cooled!in!a!variety!of!ways,!including!applying a!precooled!(i.e.,!a!temperature!less!than!the!ambient temperature)!transparent!substance!such!as!ice!or!cold gel!to!the!skin.!The!cold!substance!should!cool!the!skin before!and!during!treatment.!The!light!(electromagnetic radiation)!is!applied!to!the!skin!in!pulses!shortly!after!the application!of!the!cooling!material.!Alternatively,!the!fluid or!gel!could!be!applied!to!the!skin!or!skin!surface,!and then!cooled!(using **thermoelectric** cooler,!e.g.)!shortly before!the!application!of!the!pulsed!light!to!the!skin.

The!light!source!will **preferably!provide!a** spectrum such!that!the!optical!depth!of!penetration!into!the!tissue is!of!the!order!of!lmm!or!more.!Also,!the!light!source!will preferably **be!able!to!provide** pulses!having!fluences **of** the!order!of!100J/cm^2 and **peak!power!of** the!order!of 1000W/cm^2. A!spot!size!of!the!order!of!10mm!Is!preferable,!to!reduce!scattering!losses.

Laser!light!sources!that!should!be **appropriate** Include!a!Nd(Yag)!laser,!a!ruby!laser,!an!alexandrite!laser, diode!lasers!and!others!will!be!suitable.!Incoherent!light sources!such!as!a!xenon!flashlamp!should!also!be!**appropriate**.

A!method!for!cutaneous!resurfacing!(skin!rejuvenation)!in!accordance!with!the!present!Invention!includes use!of!an!Er:YAG!laser!light,!which!has!a!most!efficient **wavelength!of!2.94µm.!Because!the!absorption!depth** of!an!Er:YAG!laser!in!skin!Is!very!small!(less!than!20 microns),!it!may!be!difficult!to!ablate!to!a!depth!of!the order!of!100!microns!or!more!(typical!of!the!epidermis) with!it.!However,!a!deeper!depth!of!peeling!can!be achieved!by!extending!the!pulse!length!of!the!laser. While!this!Is!hard!to!achieve!using!an!Er.YAG!laser!due to!the!inherent!short!level!lifetime,!by!providing!a!few pulses!with!a!variable!delay!between!the!pulses!this!limitation!may!be!overcome.!Evaporated!tissue!layer!thickness!may!be!controlled!by!the!number!of!pulses!and variation!of!pulse **parameters** and!delay!between!pulses.!The!invention!also!relates!to!an!apparatus!using!a flashlamp!light!source,!or!any!other!source!with!appropriate!parameters,!for!smoothing!wrinkles,!without!damaging!the!epidermis.!Also,!an!ErYAG!laser!is!used!for efficient!skin!rejuvenation!by!removal!of!the!epidermis.

Generally,!the!device!Includes!a!flashlamp!that!can provide!a!pulsed!light!in!the!range!of!600-1200nm!for heating!of!collagen,!a!filter!system!that!can!cut!off!the radiation!spectrum!below!approximately!600nm,!a!light guide!that!can!provide!an **appropriate** spot!size!and!can provide!fluences!of!the!order!of!100!J/cm^2, and!an!Er.YAG!laser!with!pulse!energy!of!the!order!of!1J,!which can!be!operated!in!multiple!pulse!mode!with!delays!between!pulses!of!less!than!50msec!for!skin!rejuvenation (by!skin!ablative!peeling).

In!one **alternative** a!light!source!such!as!a!Nd(Yag) laser!or!ruby!laser!with!appropriate!parameters!could replace!the!flashlamp.

This!apparatus!is!very!useful!for!wrinkle!removal and!skin!rejuvenation.!A!flashlamp!light!source,!particularly!when!used!with!extemal!cooling!of!skin!surface, will!generate!a!temperature!distribution!inside!the!skirt which!has!a!maximum!at!depth!dependent!on!the!light and!cooling.!Consequently,!it!is!possible!to!heat!collagen!molecules!without!damaging!the!epidermis.!The temperature!distribution!In!the!skin!is!responsive!to!the delay!time!between!the!cooling!and!application!of!light, selection!of!pulse!parameters!and!the!radiation!spectrum.!Accordingly,!appropriate!control!of!these!parameters!allows!control!of!the!temperature!distribution.!An!Er.YAG!laser!operated!in!multiple!pulse!mode!Is!very!efficient!for!cutaneous!resurfacing **procedures** and!also!enables!control!of!depth!of **evaporation**. Thus,!the **apparatus!Is!safe!with!little!risk!of!accidental!injury!to!the!op-**

orator and patient.

As stated **above**, wrinkles may **be smoothed by** shrinking collagen molecules using pulsed heating. The present Invention method Is realized by heating of tissue to depths of up to a few millimeters by light radiation In association with external cooling of skin outer surface to avoid **overheating** of epidermis. The epidermis may be cooled using many methods. One **preferred** method is the application of a previously cooled transparent matter like ice or cold gel on the skin which cools the skin before and during treatment. A **temperature** distribution inside the skin similar to one shown in Figure 1 is created a short time (of the order of 1 second) after the application of the cooled material.

As may be seen, the distribution is such that the epidermis and the outer layer of the skin are colder than the more deeper part of the skin. However, the applied light heats up the superficial parts of the skin more than the inner parts, because of the attenuation of light energy fluence by depth, and due to higher absorption of light by the epidermis.

After heating a temperature distribution such as that shown In Figure 2 results. As may be seen, the deeper parts of the tissue are heated up to a temperature sufficient to cause collagen shrinking, but without damaging the outer parts of the skin (epidermis).

The **temperature** distribution generated prior to the application of light (Figure 1) is a function of the Initial temperature of the cooling material and the delay time between the application of the cooling material and the application of light. By varying this time the depth of penetration of the 'cool front ' can be varied. When collagen that is deeper needs to be treated without influencing the superficial skin, a longer delay time between the application of the coolant and the light can be used. When the superficial collagen needs to be treated, a shorter delay time can be used.

In a typical treatment the doctor applies the cold gel to the skin before treatment and then applies the light source. In accordance with one embodiment of the invention, the treatment device Indicates to the doctor when the light source needs to be applied after application of the cooling material, to achieve a desired temperature distribution. A microprocessor that controls the light generating device may also generate a timing signal for the doctor to accomplish this aspect of the invention.

The applicants *have* determined that a light source having the following parameters is suitable for implementing the invention.

Light radiation should penetrate into a tissue at a millimeter depth. Examples of light sources which meet the parameter include flashlamp, diode laser, Nd(Yag) laser and ruby laser.

Optical power should be on the order of 100-1000 W/cm^2.

Fuuence should be on the order of 30-150 J/cm^2.

Spot size should be on the order of a few millimeters to some centimeters, preferably variable over a range.

A **detailed** description of one **preferred embodiment** will be described with reference to Figure 3. As shown in Figure 3, a treatment device 300 Includes a flashlamp 301 which can be **operated** in pulse **mode**, a **reflector** 302 which forms a light beam and conducts it to a light guide 305 through a filter system **303** and **304**. **Reflector** 302 is **located** In a **treatment** head **(or housing)** 306.

Filter system 303 and 304 may Include one or more filters which cut off the radiation spectrum at approximately **550(or** 600)-800nm. Filter **303 provides** reflection of the part of unused incident radiation and avoids overheating of absorbing filter 304. Absorbing fitter cuts off radiation at approximately 550-800nm. Flexible light guide 305 can be interchanged with a rigid light guide made out of quartz or other types of high optical quality glass. Treatment head 305 is useful for treating large areas.

According to one embodiment, the light energy is applied to the skin using a train of pulses. One advantage of applying a train of pulses is that the epidermis cools relative to the layer of collagen that Is heated in the treatment. Preferably, the apparatus produces a train of pulses with variable delays between pulses in the range of 10's to 100's of milliseconds.

The total number of pulses per pulse train can also be varied. More specifically, for a patient with higher skin absorption due to heavier skin pigmentation a larger number of pulses per train is **preferably** used.

Similarly, the pulse duration of each pulse In the train can also be varied in order to enable cooling of the epidermis without cooling the collagen. In any event, the **total dose to the treated area is the product of the** number of pulses and the fluence per pulse. The pulse duration, and train length are controlled in one embodiment by a microprocessor 309. As shown on Figure 3, microprocessor 309 provides control signals to pulse forming network 310. Pulse forming network 310 (generally of the type described in **commonly owned U.S.** Patent No. 5,405,368, which is incorporated herein by reference) provides pulse to flashlamp 301.

The radiation spectrum can be controlled by filter system 303 and 304. Additionally (or alternatively), the spectrum of radiation can be controlled by varying the current density through the flashlamp. If deeper heating is required a longer wavelength radiation is used. Pulse duration may be varied in the range of a few milliseconds to a few ten 's of milliseconds.

Other embodiments of the present invention include the use of lasers (those having **proper penetration),** which can also be very **effective** to smooth wrinkles. For example, a flashlamp **pumped** Nd(Yag) laser operating at 1.06pm can provide **deep** penetration and thus be effective. The laser may be operated in the pulsed train mode, **preferably** by pulsing the flashlamps that are used to pump the laser. Similarly, a ruby laser may be used. However, the pulse duration cannot be made too long due to the limited value of the lifetime of the lasing

level of these lasers. In the laser embodiment, there is no need for filters since the light is monochromatic. Also this **embodiment does** not **require** the use of a rigid light guide since flexible light guides are readily available for laser applications and a low divergence laser beam can be easily focused into a small diameter optical fiber. The use of multiple pulses may be particularly useful to overcome the limited lasing level in the laser embodiment of the invention.

The cutaneous resurfacing method In accordance with the present Invention includes an Er..YAG laser light, whose radiation has an absorption depth of much less than that of CO_2 laser radiation, of the order of 50 micron is used. Despite the relatively low absorption depth, an appropriate peeling depth is reached by providing multiple pulses. The thickness of the layer of **evaporated** tissue may be controlled by the number of pulses, the delay between pulses and varying pulse parameters.

Er:YAG lasers produce radiation of 2.94pm, with an energy per pulse of up to 1J. Absorption depth of the radiation is typically about 10µm. Thus, to **evaporate** an epidermis, a train of pulses should be used. Typical delay between the laser pulses should be in the range of 0.5-10msec. The time should preferably be shorter than, or on the order of, the epidermis thermal relaxation time.

Thus, it should be apparent that there has been provided in accordance with the present invention a treatment device that includes a flashlamp or a near infrared pulsed laser in another embodiment, an Er:YAG laser and a coupler that fully satisfy the objectives and advantages set forth above. Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims.

Claims

1. An apparatus for treating a region of skin comprising a pulsed light source (301), a housing (306) in which the light source is disposed, wherein the housing (306) includes an aperture suitable for directing the light to the region of skin, and characterised in that the pulsed light source is capable of heating and shrinking collagen in the region of skin, thereby reviving the elasticity of the collagen and of the skin.

2. An apparatus as claimed in claim 1 further including a timing circuit coupled to the pulsed light source, adapted to indicate when a delay time has passed after an application of a cooling substance to the skin **region.**

3. **An apparatus as claimed in claim 1 or 2 further comprising a microprocessor (309) coupled to the pulsed light source** for determining the **delay** time **in response to a selected skin temperature profile.**

4. An apparatus as claimed in claim 2 or claim 3 when **appended** to claim 2 further comprising a means for reducing the temperature of the cooling substance, wherein the cooling means is **disposed to provide** a signal **indicative of cooling to the** timing circuit.

5. **An apparatus as claimed** in any one of claims 1 to 4 further comprising a pulse formation circuit and a pulse duration input, wherein the pulse duration circuit is coupled to the pulsed light source and is adapted to control the duration of pulses emitted by the pulsed light source in response to the pulse duration input.

6. An apparatus as claimed in any one of claims 1 to 5 wherein the pulsed light source includes a noncoherent light source.

7. An apparatus as claimed in any one of claims 1 to 6 further Including a filter **(303,304)** disposed adjacent to the aperture, wherein a **temperature** distribution within the skin is controlled in response to a radiation spectrum produced by filtering the light

8. An apparatus as claimed in any one of claims 1 to 7 further including a light guide **(305) disposed** adjacent to the aperture.

9. An apparatus as claimed in any one of claims 5 to 8 further including a pulse delay circuit adapted to produce a delay in the range of 0.5-10msec between successive pulses of light emitted by the pulsed light source pulses.

10. An apparatus as claimed in any one of claims 1 to 9 wherein the light source is adapted to provide pulses having energy fluences on the order of 100J/cm^2.

11. A cosmetic treatment of a region of skin comprising the steps of applying pulsed light, heating collagen and shrinking collagen, thereby reviving the elasticity of the collagen and of the skin.

12. A cosmetic treatment as claimed In claim 11 further comprising the step of protecting the epidermis and outer layers of the skin by cooling the epidermis and outer layers of the skin.

13. A cosmetic treatment as claimed in claim 12 in which the step of cooling includes the step of applying a transparent substance having a temperature less than an ambient temperature, to the region of

the! skin.

14.! A! cosmetic! treatment! as! claimed! in! claim! 13! further including! the! step! of! controlling! a! delay! time! between! the! application! of! the! substance! and! the application! of! light;! to! control! the **temperature** distribution! within! the! skin.

15.! A! cosmetic! treatment! as! claimed! in! any! one! of claims! 11! to! 14! further! comprising! the! steps! of! controlling! a! pulse! duration! and! applying! multiple! pulses! to! control! a! temperature! distribution! within! the skin.

16. A! cosmetic! treatment! as! claimed! in! any! one! of claims! 11! to! 15! wherein! the! step! of! applying! pulsed light! includes! the! step! of! pulsing! a! noncoherent! light source.

17. A! cosmetic! treatment! as! claimed! in! any! one! of claims! 11! to! 16! further! including! the! step! of! controlling! the! radiation! spectrum! by! filtering! the! light! to control! a! temperature! distribution! within! the! skin.

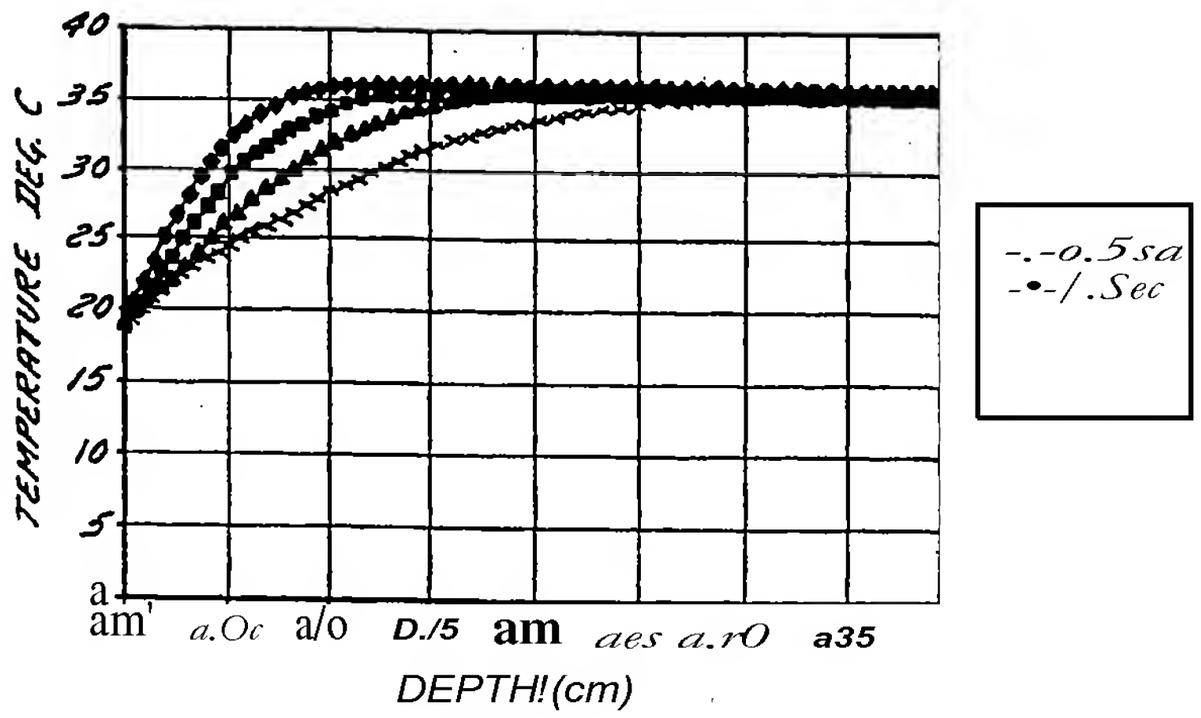
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FIG. 1

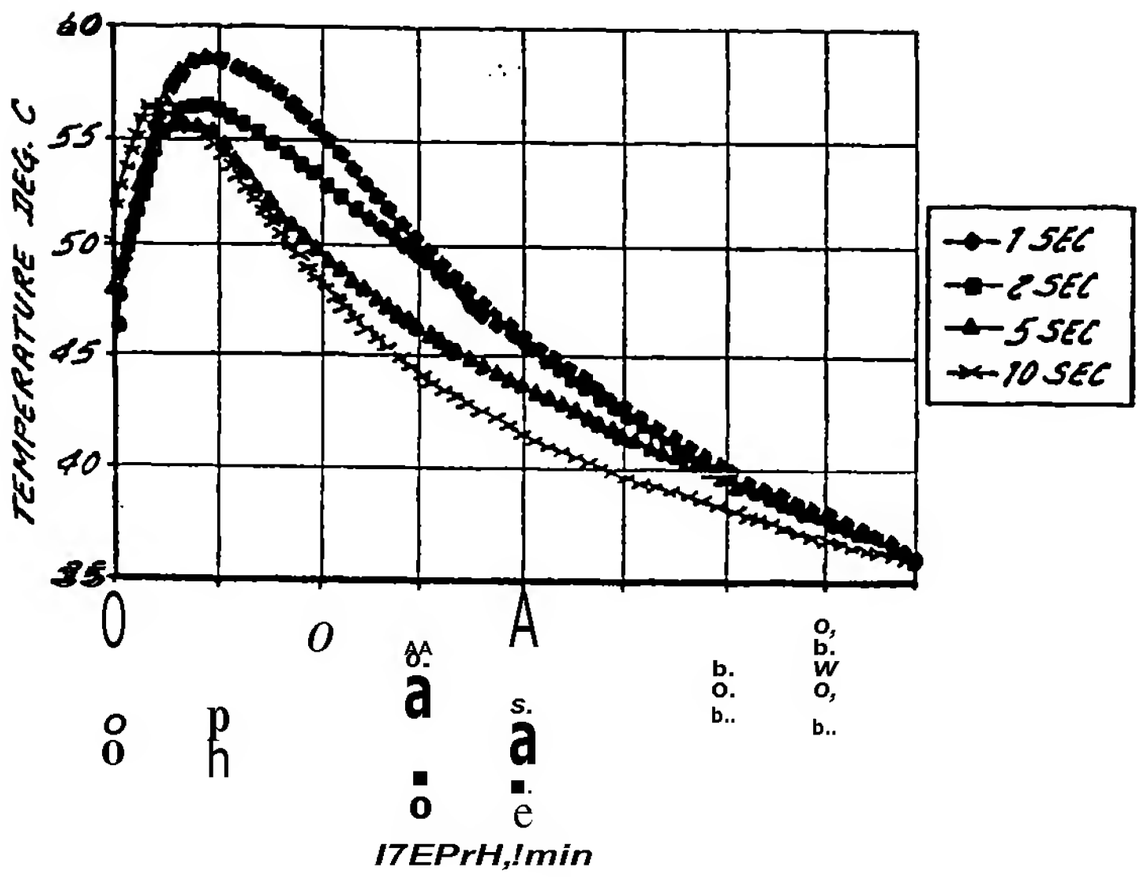
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FIG. 2

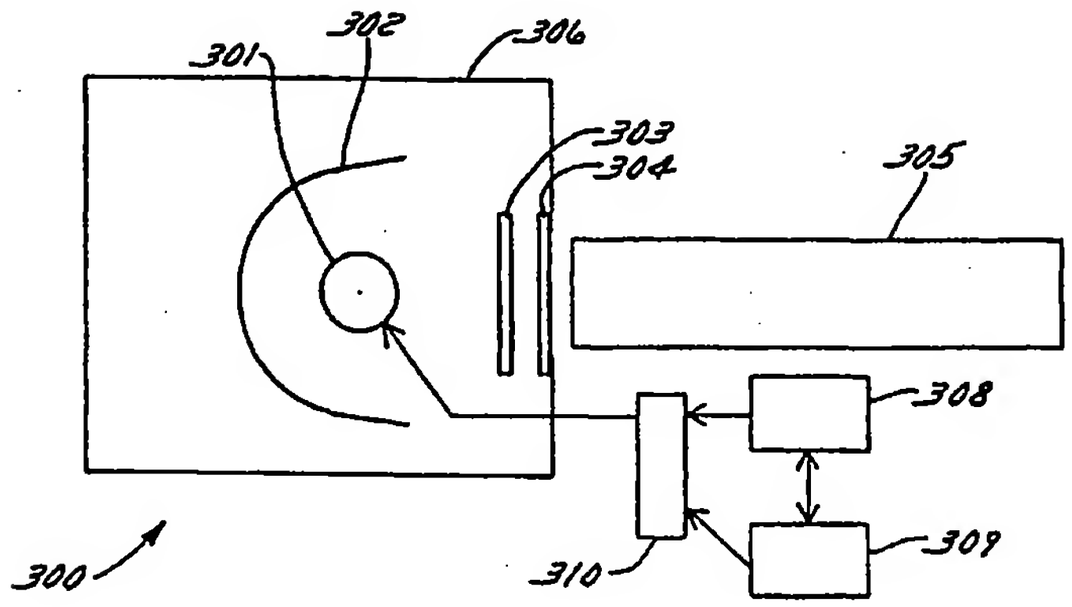
301
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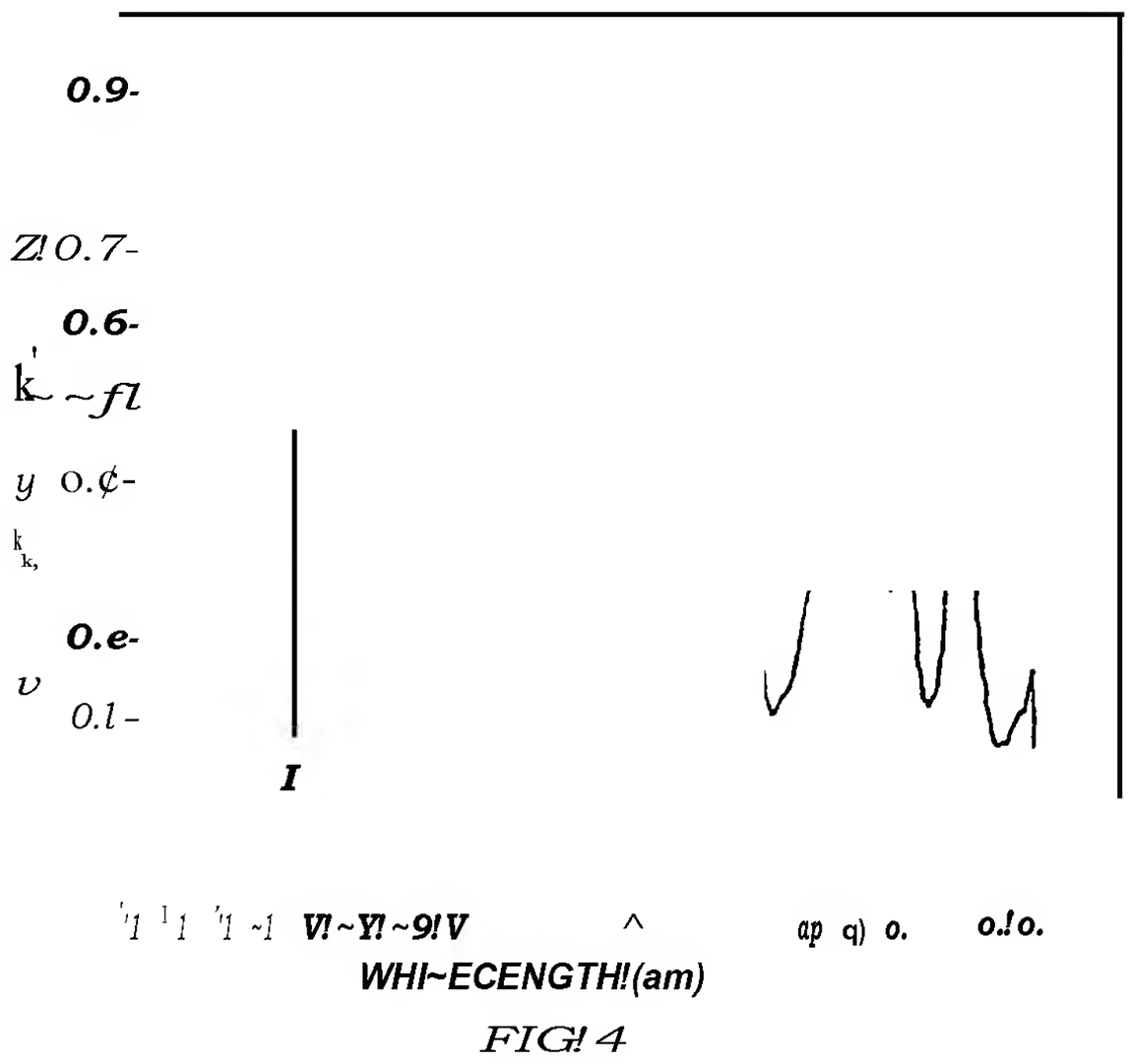
FIG. 3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FIG! 4